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Geothermal resources in Algeria

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ABSTRACT

The geothermal resources in Algeria are of low-enthalpy type. Most of these geothermal resources are located in the northeastern of the country. There are more than 240 thermal springs in Algeria. Three geothermal zones have been delineated according to some geological and thermal considerations: (1) The Tlemcenian dolomites in the northwestern part of Algeria, (2) carbonate formations in the northeastern part of Algeria and (3) the sandstone Albian reservoir in the Sahara (south of Algeria). The northeastern part of Algeria is geothermally very interesting. Two conceptual geothermal models are presented, concerning the northern and southern part of Algeria. Application of gas geothermometry to northeastern Algerian gases suggests that the reservoir temperature is around 198 °C. The quartz geothermometer when applied to thermal springs gave reservoir temperature estimates of about 120 °C. The thermal waters are currently used in balneology and in a few experimental direct uses (greenhouses and space heating). The total heat discharge from the main springs and existing wells is approximately 642 MW. The total installed capacity from producing wells and thermal springs is around 900 MW.

Contents

1. Introduction

Algeria is situated in northern Africa, bordering the Mediterranean Sea, between Morocco and Tunisia (Fig. 1). In this paper we summarize the geological setting and geothermal data of Algeria. The geothermal exploration program in Algeria started in 1967 and was undertaken by the national oil company SONATRACH. In 1982 the national electric power company SONALGAZ undertook the geothermal recognition studies of the northern and eastern parts of the country in association with the Italian company ENEL. In the first stage, the geothermal studies concerned mainly the northeastern part of Algeria. From 1983 onwards the geothermal work has been continued by the Renewable Energies Center of Algeria (CDER) and the program was extended to the whole northern part of the country. The relatively low prices of the conventional energies (natural gas and fossil fuels) and the national policy on

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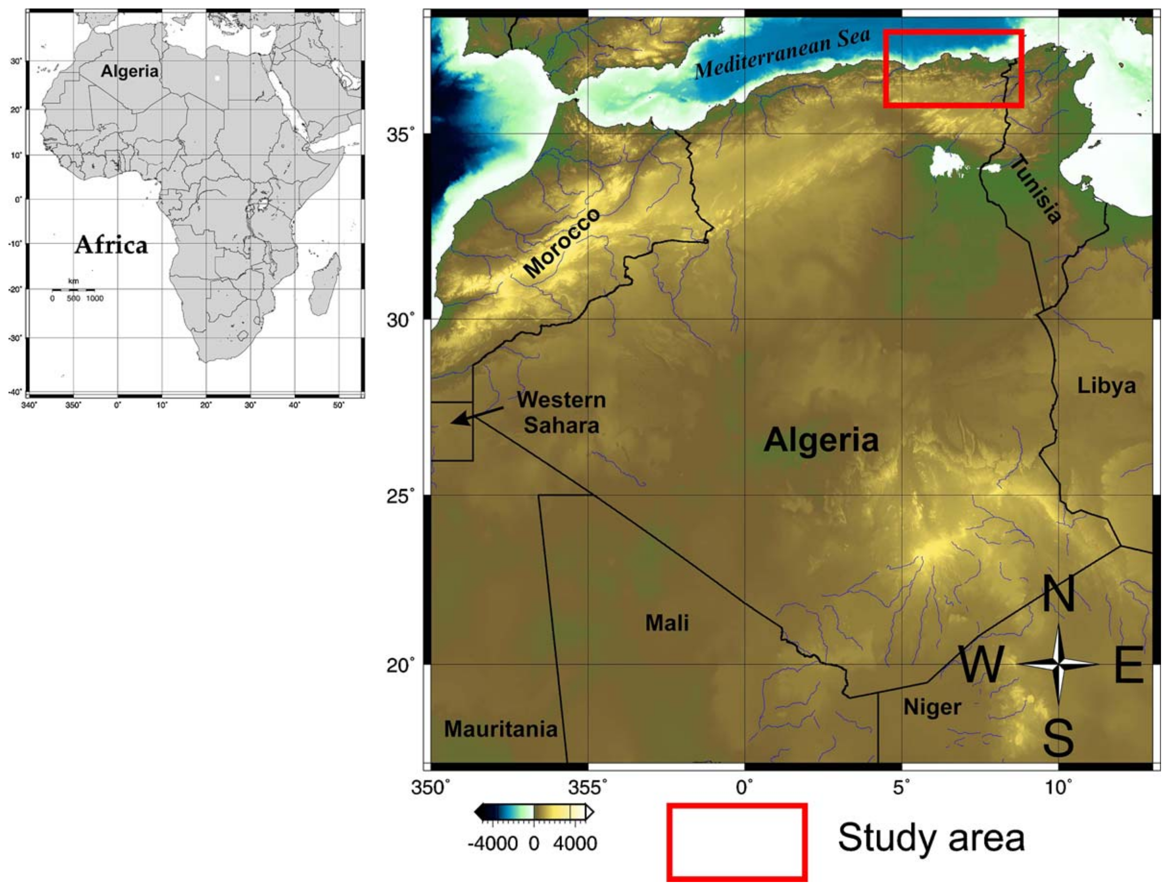

Fig. 1. Location of Algeria in Africa. The red rectangle represents the area in Fig. 9. (For interpretation of the references to color in the figure caption, the reader is referred to the web version of the article.)

rural electrification have a negative influence on the development of geothermal energy in Algeria. Geothermal development has remained stagnant during the last decade. Presently renewed effort is put into developing large projects with the establishment of the geothermal atlas of Algeria. The recent adoption of the renewable energies law by the government will certainly enhance the geothermal activities in Algeria. It is worth to mention that the term Hammam is an Arabic term for hot spring.

2. Geological context

West Africa is essentially composed of two major tectonic units (Fig. 2): the West African Precambrian Craton (WAC), stable since 2000 Ma; and the surrounding mobile belts largely of Upper Proterozoic age. The basement of the WAC exposed in the Reguibat and Leo uplifts is dominated by the occurrence of Archean nuclei surrounded by low-grade metamorphism of volcanoclastic Birrimian formations. These formations were affected by the Eburnean orogeny (approximately 2000 Ma) and intruded by numerous lower Proterozoic granitoids. The Taoudeni basin occupies the central part of the WAC, and is filled with sediments of Upper Precambrian to Paleozoic age. Changes in the gravity pattern support the subdivision of the WAC into discrete rigid crustal blocks of Archean age surrounded by accreted highly deformed Proterozoic belts [1]. The WAC is surrounded by Pan-African mobile belts (Anti-Atlas, Tuareg shield, Benin-Nigeria shield, Rockellides, Mauritanides) overlain by Paleo-Mesozoic sedimentary basins (Sahara, Niger, Tindouf). These belts resulted from collisional tectonic processes around 600 Ma [1,2]. The Tuareg shield is dominated by north-south elongated structural units, between which correlations are not always possible [3]. Gravity data correlate with these structures and outline their north-south extension within the basement beneath the Sahara and Niger basins. The Pan-African belt has been locally reactivated by the Caledonian (Mauritanides) and the Hercynian (Mauritanides, Atlas and Ougarta) orogenies. Only the northern margin of the African plate has been affected by the Alpine orogeny (Maghrebide belts). Widespread Upper Mesozoic to Cenozoic volcanism affects the Pan-African mobile belt but is absent within the WAC. This volcanism is sometimes correlated with a system of swells (Hoggar; Tibesti, southern Libya; Cameroon; Darfur, western Sudan) and troughs (Benoue, northern Cameroon; Tenere). The Hoggar is a very large (800 km) Precambrian basement swell where the mean altitude ranges from 1000 to 1500 m. Evidence from lavas and xenolith petrography, as well as heat flow and gravimetric constraints, has suggested the interpretation that this uplift is due to a now-cooled altered upper mantle emplaced during the Late Mesozoic time [4,5]. The geology of Algeria (Fig. 3) is divided into two main structural units: the folded Tellian Domain in the North, and the Saharian Platform in the South, separated by the South Atlasic Flexure [6]. The north of Algeria belongs to the Alpine structural domain (unstable) with significant seismic activity. It is characterized by complex geology of overthrusting allochthonous terrains; the geological formations are mainly carbonates and marls. The last phase of the Alpine folding of Astian age played an important role in the rejuvenation of the relief and the development of fractures as well as in the apparition of saliferous domes. Actually the Alpine phase affected only the Tellian Domain where magmatic activities appeared after the installation of the over thrusting nappes (Upper Miocene). The Saharian Platform has remained a stable zone characterized mainly by sedimentary basins which constitute the

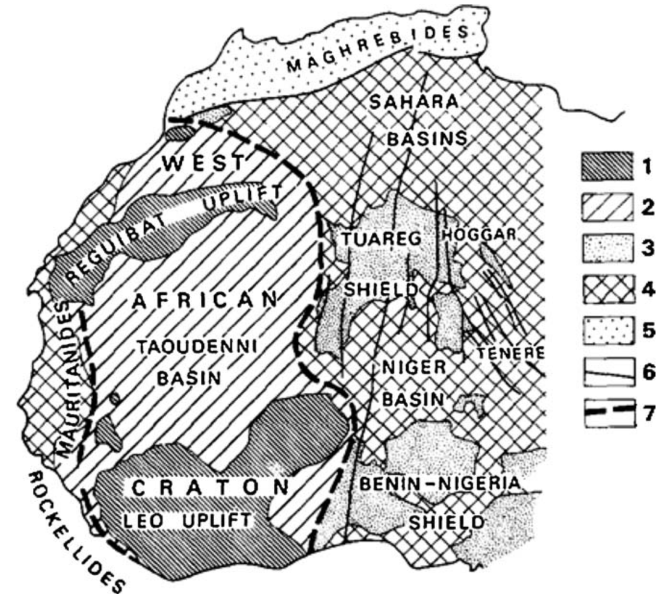

Fig. 2. Major geotectonic units of West Africa (A). 1–3 = West African craton (1 = basement, >2000 Ma; 2 = sedimentary cover; 3 = craton limit from [1]); 4, 5 = Pan-African domain (4 = basement, 600 Ma; 5 = post-Pan-African sedimentary cover); 6 = Maghrebides Alpine fold belt; 7 = Megafaults [7].

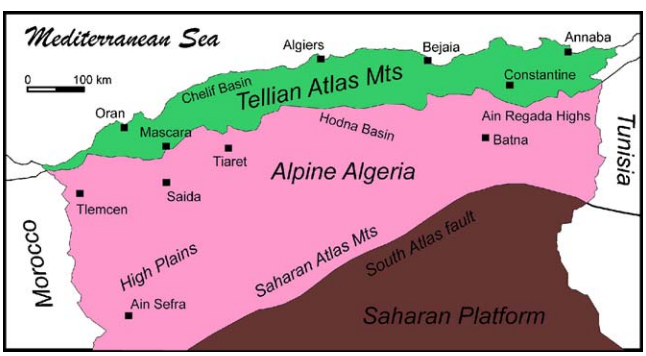

Fig. 3. Main geological formations in the northern part of Algeria (modified from [21]).

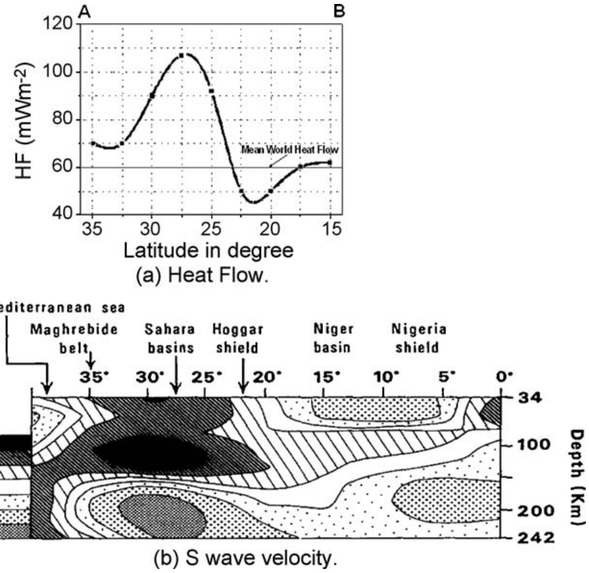

Fig. 4. Relationships between heat flow and S-wave velocities along the meridian 7°E. (a) Heat flow profile AB (see location in Fig. 1). Projection of profile on heat flow data located in a 500 km wide. (b) Cross-section of S-wave velocity variations (reference value is 4.47 km s^{-1}) (modified from [7]).

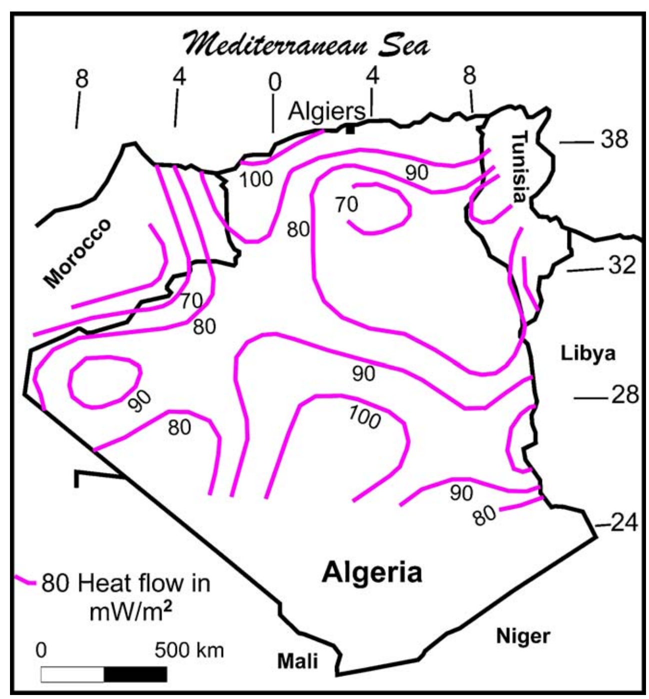

Fig. 5. Heat flow map of Algeria (modified from [26]). Unit: mW/m^2. 230 oil wells are presented, with depths ranging from 500 to 5500 m. Number of temperature measurements vary between 3 and 15.

hydrocarbon reservoirs and the Albian geothermal aquifer. To the South, in the Hoggar region, magmatic activities took place from the Miocene to the Quaternary.

3. Heat flow map of Algeria

Evaluation of heat flow in 230 oil wells, using temperature measurements (bottom-hole temperature T_{BHT} and temperature of fluids in drill stem test T_{DST}) and various rock-porosity data reveal a high heat flow average (82 ± 19 mW/m^2) associated with the Algerian Sahara basins. The high heat flow anomaly of the Algerian Sahara basins correlates well with a low S-wave velocity zone (Fig. 4) and locally with a low-amplitude negative gravity anomaly [7]. The heat flow distribution map (Fig. 5) exhibits significant regional variations overprinted by short-wavelength anomalies that, in general, are related to the local geological structure. On a regional scale, there is an essentially north-south zonation that is not directly related to the major structural units, except for the northern Alpine domain. The southern area, at the border of the Hoggar Precambrian basement, is characterized by very high heat flow values (90–130 mW/m^2) correlated with lithospheric and asthenospheric processes. The anomalies define a major axis, generally east-west, which seems to affect the northern part of the African plate, from the Canaries (volcanic Islands located between latitudes 27°N and 30°N, with its eastern edge only 100 km from the NW African coast) to Libya (see Fig. 1). Locally, some relationships with extensional Miocene–Pliocene–Quaternary volcanism suggest an association with recent mantle thermal events.

Fig. 6 shows the distribution of temperature with depth. The Central Sahara, where most of measurements are located, shows a small dispersion around a mean gradient of 21 °C km^{-1}. On the other hand, the two other regions show large dispersions around

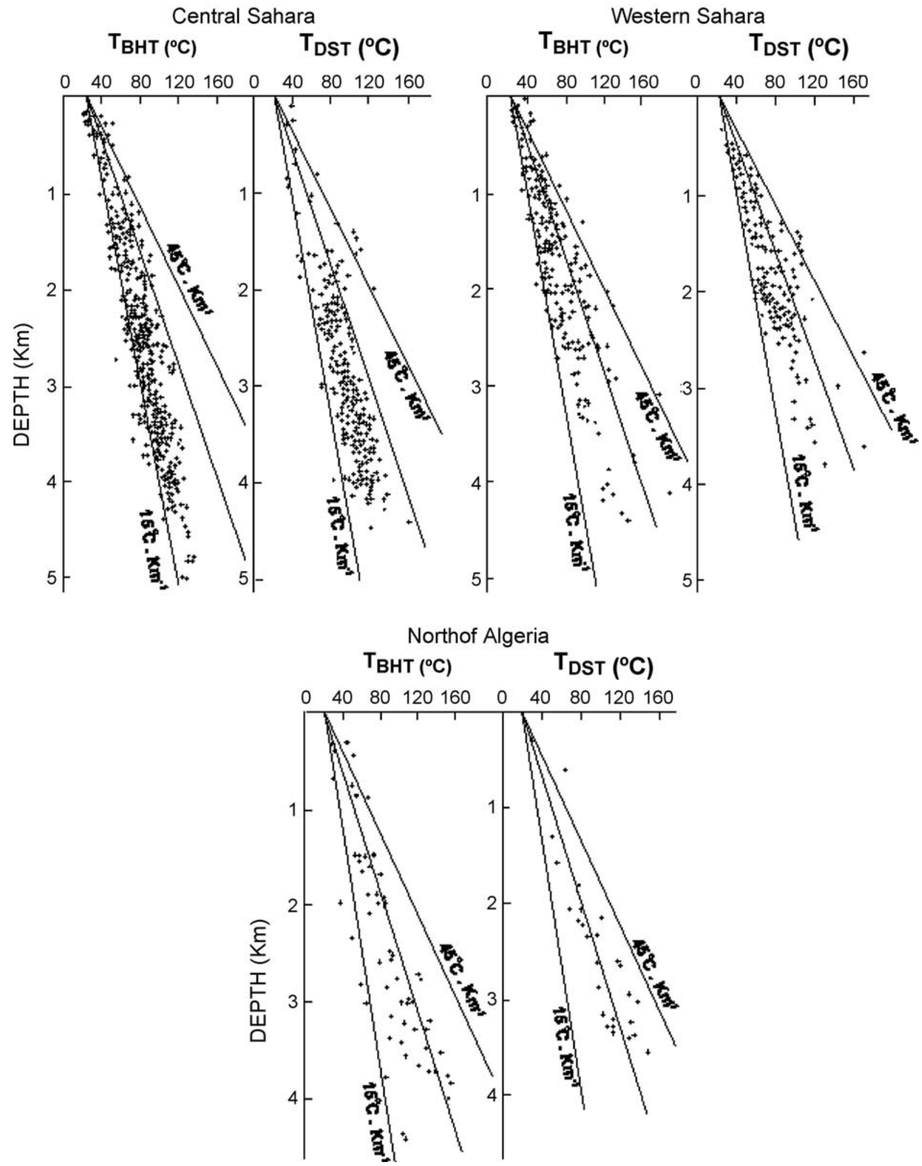

Fig. 6. Plots of T_{BHT} and T_{DST} versus depth for different regions (modified from [26]).

mean gradients of 32 °C km^{-1} for the Western Sahara and 26 °C km^{-1} for northern Algeria. Fig. 7 shows the geothermal gradient in northern Algeria.

4. Geothermal areas and reservoirs

The inventory of the thermal springs has been updated to show more than 240 sites. The temperatures of Algerian hot waters vary from 22 to 98 °C. The highest spring temperatures recorded are: 68 °C for the western area (Hammam Bouhnifia), 80 °C for the central area (Hammam El Biban) and 98 °C for the eastern area (Hammam Meskhoutine) in northern Algeria (Fig. 7). In the southern area, there are some thermal springs with a mean temperature of 50 °C. The total dissolved solids (TDS) of the hot springs in northern Algeria are greater than 1 g/L (Fig. 8). Carbonate formations constitute the main geothermal reservoirs in northern Algeria, while in southern Algeria the reservoirs are dominantly composed of sandstone. Three geothermal regions have been delineated according to the distribution of thermal springs and geological and geophysical considerations (such as permeability and geothermal gradient). Fig. 8 shows the location of the three geothermal regions of Algeria.

4.1. The Tlemcenian dolomites in the northwestern area

According to the chemical types of the waters, this northwestern area can be divided into two zones: a southern zone is

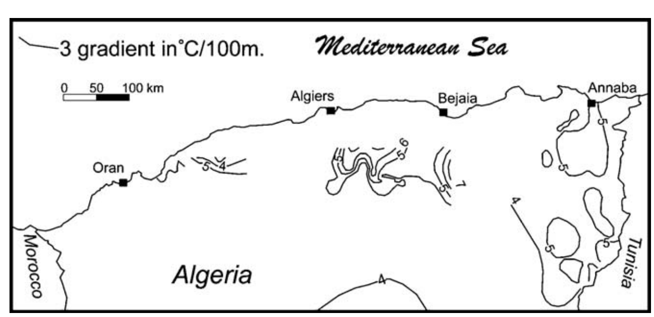

Fig. 7. Geothermal gradient in the northern part of Algeria (modified from [21]).

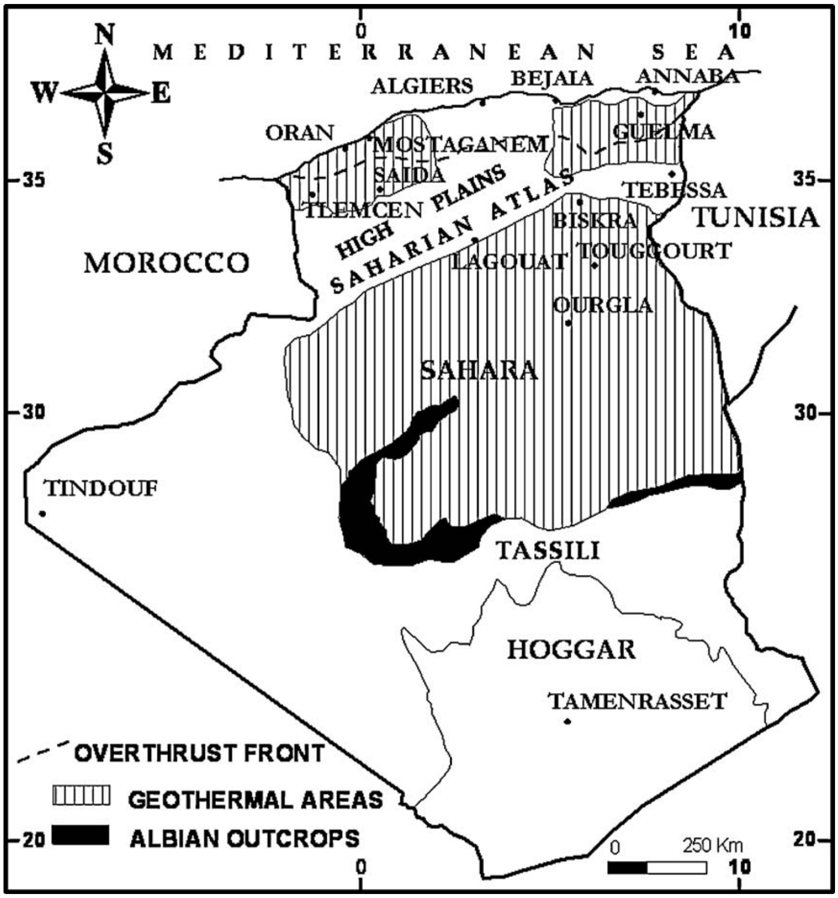

Fig. 8. Main geothermal areas (modified from [11]).

characterized by homogenous geological formations (dolomites and carbonates) and dominantly Ca–HCO_3-rich waters. The northern zone is set on allochthonous terrains. The thermal springs have a variety of chemical types. The studies of the former zone gave little information about the reservoir and the thermal water origin. Verdeil [8] and Blavoux and Collignon [9] have established a close relationship between the thermal springs and the seismicity of the area. The isotopic data, particularly ^{13}C and

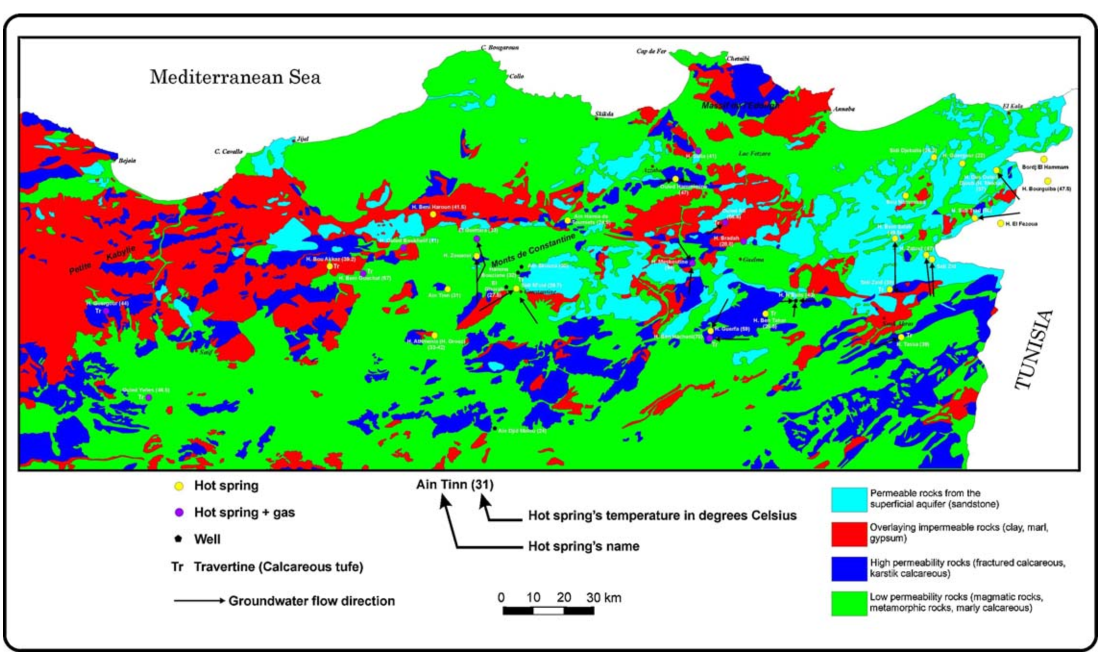

Fig. 9. Hydrogeologic map of the northeastern part of Algeria showing the location of the hot springs with their surface temperatures and the direction of the groundwater flow (modified from [12]).

^{18}O, show that the waters are of a deep origin [9]. Fenet [10] indicated that the main thermal springs originated from deep transverse faults. The Plio-Quaternary volcanic rocks in the coastal zone could be related to the thermal waters such as at Hammam Bouhadjar and Hammam Bouhnifia [11]. To the South of this zone, the Jurassic dolomites of Tlemcen on the Tlemcen-Saida axis constitute a shallow reservoir. About fifteen thermal springs whose temperatures range from 25 to 47 °C have been recorded as bicarbonate water type [9].

4.2. Carbonate formations in the northeastern area

This area covers approximately 15,000 km^2 and consists of mainly carbonate formations. In the northeastern part of Algeria, the Neritique Constantinois formations and the carbonate part of the Tellian sheet form the reservoirs of Guelma and Bouhadjar, respectively [12]. This area is characterized by springs of high flow rates, i.e. more than 100 L/s for Hammam Barda and by the highest temperature in the country (98 °C for Hammam Maskhoutine, see Fig. 9). The thermal waters in this area are chemically dominated by chloride and sulphate, and have TDS ranging between 1.6 and 2.2 g/L. Two prospects have been chosen for more detailed investigations where geothermal reservoirs could exist at different depths [12]. On the basis of ^{18}O and ^{2}H analyses performed on waters from the northeastern areas, the thermal waters are of meteoric origin [13].

4.3. Albian sandstone reservoir in the Sahara area (south of Algeria)

Thermal springs are scarce in this area. The Albian aquifer is exploited by the wells mainly for domestic and agricultural purposes. The sandstone Continental Intercalary formation constitutes the reservoir for the Albian aquifer, covering an area of 600,000 km^2 [14]. This reservoir outcrops in its southern part and dips towards the north to reach a depth of 2600 m in the Biskra region. This reservoir is covered by calcareous formations which yield the chemical characteristics of the water type (CaNa–SO_4Cl) with a mean TDS of 1.5 g/L.

5. Gas chemistry of northeastern Algeria

In northeastern Algeria there are numerous thermo-mineral springs. The most important one is Hammam Meskhoutine, which has a maximum temperature of 98 °C, and is situated on the faults. A helium isotopic study shows the existence of a magmatic signal at depth [15]. Analyses of 12 spring gases are presented in Table 1. The principal gases are CO_2 and N_2. In comparing the N_2/O_2 ratios of different springs with that of air (Table 1), we observe that most springs have high N_2/O_2 ratios except for the following: Hammam N'Bail, Hammam Sidi Djaballah and Hammam El-Hamma, which have values near those of air and have high oxygen concentrations. This indicates atmospheric contamination at the time of sampling or organic contamination. The He/Ar ratios are greater than the atmospheric value of 5.7×10^{-4}, which means that the source of He is radiogenic. The N_2/Ar ratios of all analyzed springs are between 38 and 84, which are the values of air-saturated water and free air (Table 1). This leads us to conclude that the N_2 and Ar features of these springs are of atmospheric origin. A mixing model of the proportions of N_2, He, and Ar proposed by Giggenbach [16] has been applied to produce a diagnostic ternary plot to aid identification of sources of the gases (Fig. 10). The results show that all hot springs are located around the meteoric origin corner except Hammam Biban, which has some contributions from crustal sources. The CO_2–H_2S–H_2–CH_4 geothermometer proposed by D'Armore and Panichi [17] has

Table 1
Chemical data for samples (northeastern Algeria). The data are in micromole/mol. G signifies gas (free gaseous phase) and W water (dissolved gaseous phase evacuated) in this case, the total number of moles of gas is given [15].

Name of the hot spring	T (°C)	Phase	Mol/L	CO_2	H_2S	CH_4	H_2	N_2	O_2	Ar	He	N_2/O_2	N_2/Ar	He/Ar	P_{CO_2}	CO_2–H_2S–H_2–CH_4 geothermometer (T, °C)
Biban	77.5	G	-	932,000	58,000	3900	-	5,000	47	75	16	106	67	0.213	1	ND
Ouled Yelles	48.4	G	-	341,00	7200	1600	168	934,500	11,000	11,400	895	85	82	0.079	0.1	313.20
Soukhna	46.4	G	-	31,200	-	1160	4	953,000	950	13,000	260	1003	73	0.020	0.1	ND
Benhachani	71.7	G	-	774,000	9000	9700	35	204,000	-	2,900	83	-	70	0.029	10	75.36
Chellala	94.3	G	-	994,900	1400	460	-	4,100	110	110	0.46	37	37	0.004	1	ND
N'Bail	42.7	W	6.80E−04	570,400	-	-	300	337,000	85,000	7,800	22	4	43	0.003	0.1	ND
Beni Salah	36.3	W	4.51E−04	825,000	1800	1200	-	167,000	-	4,800	13	-	35	0.003	1	ND
Sidi Djaballah	25.4	G	-	13,400	-	-	160	831,500	145,000	9,500	61	5.7	88	0.006	0.1	ND
Meksa	38	W	7.50E−04	386,200	2650	-	570	593,800	2,900	15,100	133	205	39	0.009	0.1	ND
Salihine	48.1	G	-	39,600	39	54	17	680,900	39	9,840	80	-	69	0.008	0.1	198.52
El Hamma	35.7	W	1.70E−04	484,000	-	-	67	378,000	131,000	6,700	49	2.9	56	0.007	0.1	ND
Beni Haroun	41.1	G	-	60,600	1050	-	-	874,700	52,400	11,100	108	17	79	0.010	0.1	ND
Air	-	-	-	330	Var.	Var.	Var.	780,840	209,480	9,340	5.24	3.7	84	0.001	-	-

ND: not determined.

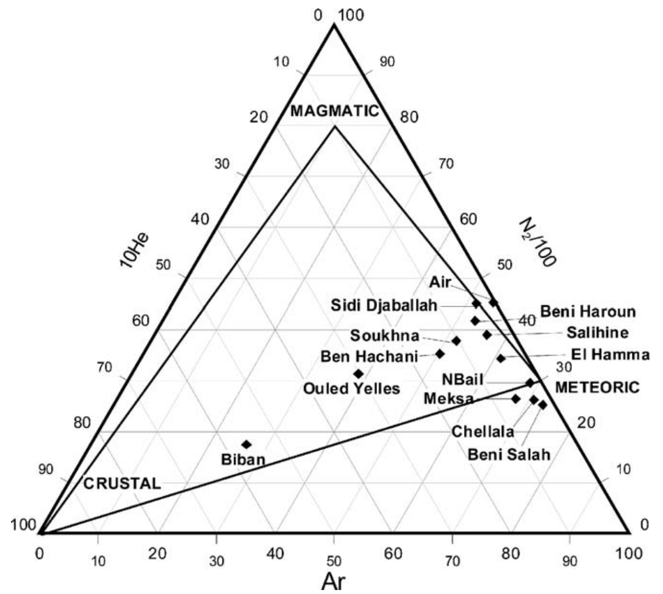

Fig. 10. Mixing model to illustrate the relative contribution of magmatic, meteoric and crustal sources of gases in northeastern Algerian geothermal discharges.

been applied to estimate the reservoir temperature of the hot springs of the northeastern part of Algeria. The geothermometry equation is:

$$T(^\circ C) = \frac{24,775}{2\log(CH_4/CO_2) - 6\log(H_2/CO_2) - 3\log(H_2S/CO_2) + 7\log P_{CO_2} + 36.05} - 273$$

The partial pressure of carbon dioxide is related to the proportion of carbon in the total gas content of the discharge: if $CO_2 < 75\%$, $P_{CO_2} = 0.1$; if $CO_2 > 75\%$, $P_{CO_2} = 1.0$; if $CO_2 > 75\%$ and $CH_4 > 2H_2$ and $H_2S > 2H_2$, $P_{CO_2} = 10$. The results are presented in Table 1. Only three reservoir temperatures could be calculated. The reservoir temperature of 75 °C for the Benhachani hot spring is underestimated. The two other reservoir temperatures are 313 °C for Ouled Yelles hot spring and 198 °C for the Salihine hot spring. We decide to take 198 °C as the reservoir temperature of the northeastern Algerian hot springs. The penetration depth of water in the northeastern part of Algeria can be estimated using the geothermometry results and heat flow data. The heat flow in northeastern Algeria is high, around 90–100 mW/m^2. If we assume that the average annual atmospheric temperature is 15 °C, a reservoir temperature of 198 °C, and a geothermal gradient of 26 °C km^{-1}, the calculated penetration depth is 7 km, which explains the deeply circulating water.

6. Silica and cation geothermometers

The temperatures of the northeastern hot springs from the study area were calculated using the following geothermometers: a Na–K–Ca geothermometer with Mg-correction [28], a cationic composition geothermometer (CCG) [29], silica [30], and Na/Li [31]. The CCG is considered to be a good method of temperature estimation [18]. Table 2 estimates the reservoir temperatures of the samples.

The highest estimated reservoir temperatures are indicated by the CCG geothermometer (Table 2). The lowest temperature estimate is given by silica geothermometer, which could be explained by silica precipitation during sampling or mixing with water that has low silica contents [19]. The Na–K–Ca geothermometer measured temperatures are lower than those measured by CCG, which is due to slightly high Mg contents in the sample. The Mg levels in high temperature geothermal fluids are usually very low (0.01–0.1 mg/L) [20], while in the northeastern Algerian samples, the Mg content ranges between 1.5 mg/L (Beni Salah hot spring, see [21]) and 137 mg/L (N'Bails hot spring, see [21]). The high Mg concentrations can indicate near-surface reactions that leach Mg from the local rock, or dilution by Mg-rich groundwater [20] (Fig. 11).

Table 2
Estimated reservoir temperatures (in °C) based on geothermometric data for some thermal springs of northeastern Algeria.

Hot spring	$T_{discharge}$	T_{Quartz}	T_{CCG}	$T_{Na-K-Ca}$[a]	T_{Na-Li}
Chellala	94	122.28	236.02	136.76	188.51
N'Bails	40	79.78	166.03	112.22	141.88
Hamimine	47	79.78	169.52	113.74	–
Zaid	38	67.38	151.41	77.68	160.96
Ben Hachani	72	110.67	215.41	157.13	260.83
Zatout	47	91.96	116.28	57.97	109.26
Guerfa	59	105.37	203.85	135.32	174.06
Ben Tahar	28.5	85.79	212.56	142.19	187.33
Beni Salah	49.5	106.75	179.49	136.20	117.93
Tassa	39	69.49	148.79	100.95	156.20
Ouled Ali	56.5	102.59	232.66	172.48	231.60
El Hamma	27.8	50.59	142.86	92.04	–
Meksa	37	91.41	198.49	121.30	158.67
Sidi Trad	60	102.49	214.15	131.90	168.29
Sidi Djaballah	36.3	84.03	144.67	80.18	186.96

[a] $T_{Na-K-Ca}$: the Δt_{Mg} is negative so the Mg-correction could not be applied. The discharge temperatures and chemical data of the hot springs are from [32] referenced by Kedaid [21].

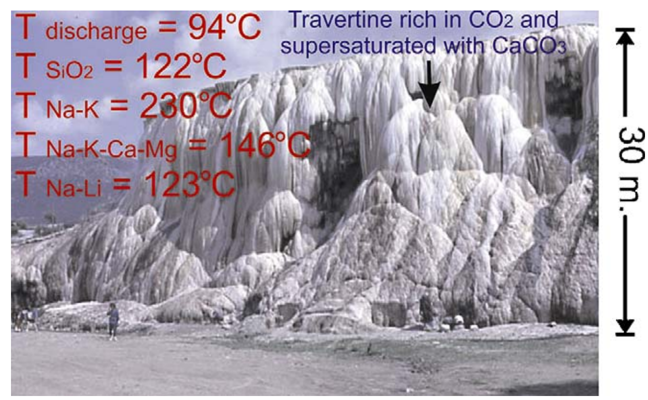

Fig. 11. Photo of the concretions of Hammam Meskhoutine (northeastern Algeria). The height of the concretions on successive conduits reaches 30 m.

7. Heat discharge evaluation

In order to quantify the energy potential better, which is immediately available for direct use, we have made a preliminary evaluation of the heat discharge from the main hot springs and from the exploited wells of the Albian aquifer (Table 3).

The mean annual atmospheric temperatures used for the calculations are 18 °C for the northern areas and 30 °C for the

Table 3
Evaluated heat discharge of Algeria [11].

Geothermal regions	Flow rate (Q, L/s)	Evaluated heat discharge (MW)
North-west	800	60
North-east	700	79
South	4000	503
Total	5500	642

Table 4
Utilization of geothermal energy for direct heat as of 31st December 2004 (other than heat pumps) [11,27].

Locality	Type[a]	Maximum utilization					Capacity[c] (MW)	Annual utilization		
		Flow rate (kg/s)	Temperature (°C)		Enthalpy[b] (kJ/kg)			Average flow (kg/s)	Energy[d] (TJ/y)	Capacity factor[e]
			Inlet	Outlet	Inlet	Outlet				
Maskhoutine	B	80	90	20			23	50	330	
Oulad Ali	B	83	50	20			10.8			
Ain Berda	B	100	28	20			3.4	100	26.4	
Soukhna	B	83	50	20			10.4	80	316.8	
Mohammadia	B	12	47	20			1.35			
Teleghma	B	10	48	20			1.17			
Bougharara	B	7	37	20			0.5			
Bouhanifia	B, D	9	68	20			1.8			
Chiguer	B	5	35	20			0.3			
Bouhadjar	B	5	64	20			0.9	10	33	
Rabi	B	6	47	20			0.7			
El Biban	B	2	80	20			0.5	10	72.6	
Essalihine	B	65	43	20			6.3			
N'Bail	B							8	14.8	
Total							61	258	793.6	

Note: The capacity factor must be less or equal to 1 and is usually less, since projects do not operate at 100% of capacity all year.
[a] D: district heating (other than heat pumps); B: heating and swimming (including balneology).
[b] Enthalpy information is given only if there is steam or two-phase flow.
[c] Capacity (MW) = maximum flow rate (kg/s) [inlet temperature (°C) − outlet temperature (°C)] × 0.004184 or = maximum flow rate (kg/s) × [inlet enthalpy (kJ/kg) − outlet enthalpy (kJ/kg)] × 0.01.
[d] Energy use (TJ/y) = average flow rate (kg/s) × [inlet temperature (°C) − outlet temperature (°C)] × 0.1319 (TJ = 1012 J) or = average flow rate (kg/s) × [inlet enthalpy (kJ/kg) − outlet enthalpy (kJ/kg)] × 0.03154.
[e] Capacity factor = [annual energy use (TJ/y)/capacity (MW)] × 0.03171.

South. The flow rates are taken from Blavoux and Collignon [9] for the northwestern area; from Dib [22] and SONALGAZ [12] for the eastern area and from Conrad [14] for the South.

8. Direct uses

For practical reasons, the Ouargla and Touggourt sites (north-eastern of the Algerian Sahara) have been chosen for the experimental greenhouses/geothermal heating systems [23]. These greenhouses are used for melon and tomato cultivation. Even though the Sahara area is characterized by hot weather, important temperature variations are recorded during the winter, and the summer seasons where the night temperatures could reach a value below 0 °C. Eighteen greenhouses covering a total surface of 7200 m^2 are heated by the 57 °C Albian geothermal water. The source temperature combined to a flow rate of 1 L/s is used to assure a minimum temperature of 12 °C inside every greenhouse. The heating system, which is a reserve flow type, has been operating since 1992. The polypropylene tubes are put directly on the ground close to the plants. The main results are precocity of 20 days and an increase of 50% in production, compared to that of the unheated greenhouses. Bellache et al. [24] states that the geothermal potential in these regions is sufficient to heat 9000 greenhouses, with a flow of 3421 L/s. The Table 4 is incomplete; however, there are average flow rates and energy use for six of the localities amounting to 258 kg/s and 793 TJ/y, respectively. Using these numbers as a basis, it is estimated that for the total of eleven localities used for bathing together with the amounts quoted for greenhouse usage, the total flow would be about 550 kg/s and an energy utilization 1657 TJ/y, which gives a thermal power of about 100 MW with a load factor for bathing of approximately 0.5 [25].

9. Discussion

The existence of hot spots in the Hoggar zone, longitude 6°E and latitude 23°N and in Canary Islands, longitude 17°W and latitude 28°N may explain the east-west elongated high heat flow anomaly. For northern Algeria, we proposed the following conceptual model (Fig. 12A). The meteoric water goes downward through deep fractures, and is heated from below by a slightly high conductive

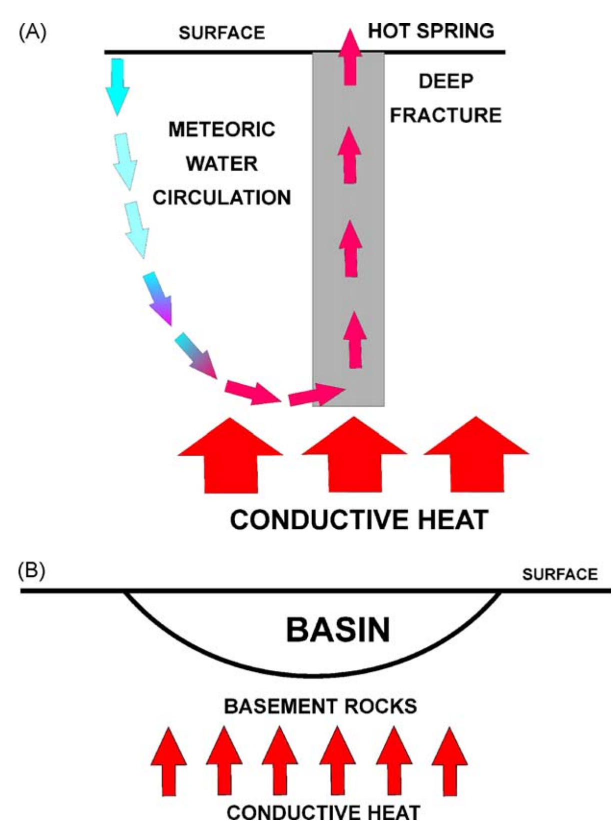

Fig. 12. (A) Idealized northern Algerian geothermal system, characterized by heating of the filtered meteoric water. (B) Idealized southern Algerian geothermal system, characterized by basement heating of the sedimentary basin.

heat flow; then the heated water rises to the surface and produce the hot springs. The temperature of the hot springs depends on the velocity of water flow, time of circulation and fracture characteristics. For the southern Algerian case, a sedimentary basin type geothermal system is assumed (Fig. 12B). The water in the pore of the sedimentary rocks is heated by conductive heat flow from below. Almost no circulation of water occurs, and the reservoir exhibits very high pressure creating a geopressured system. Southern Algeria consists of Quaternary basins.

10. Conclusions

The inventory of thermal springs has been updated with more than 240 springs identified. The highest temperatures recorded were 68 °C for the western area, 80 °C for the central area, and 98 °C for the eastern area. In the south, the thermal springs have a mean temperature of 50 °C. The northeastern zone of the country, covering an area of 15,000 km^2, remains potentially the most interesting geothermal area, with the Barda spring giving 100 L/s, and another spring in the area having the highest temperature in the country (98 °C). An estimate of the heat discharge from about 30% of the country's springs is 642 MW based on a mean annual atmospheric temperature of 18 °C for the northern areas and 30 °C for the central or Sahara area. Some greenhouses at Ouargla and Touggourt in the central region are reported to be using about 60 °C geothermal water for heating. We recommend further use of the country's geothermal resources to improve food production, especially the use of greenhouses outside the conventional periods when the climate requires heated greenhouses to enhance growth (during the severe climatic conditions from October to March). Despite the determination of the three main geothermal areas, more detailed studies are needed to delineate the reservoirs and to evaluate their potentials.

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